

A 90 GHZ PHOTOINJECTOR*

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Abstract

Photocathode rf guns depend on mode locked laser systems to produce an electron beam at a given phase of the rf. In general, the laser pulse is less than $\sigma_z = 10^\circ$ of rf phase in length and the required stability is on the order of $\Delta\phi = 1^\circ$. At 90 GHz (W-band), these requirements correspond to $\sigma_z = 333$ fsec and $\Delta\phi = 33$ fsec. Laser system with pulse lengths in the fsec regime are commercially available, the timing stability is a major concern. We propose a multi-cell W-band photoinjector that does not require a mode locked laser system. Thereby eliminating the stability requirements at W-band. The laser pulse is allowed to be many rf periods long. In principle, the photoinjector can now be considered as a thermionic rf gun. Instead of using an alpha magnet to compress the electron bunch, which would have a detrimental effect on the transverse phase space quality due to longitudinal phase space mixing, we propose to use long pulse laser system and a pair of undulators to produce a low emittance, high current, ultra-short electron bunch for beam dynamics experiments in the 90 GHz regime.

1 INTRODUCTION

In this paper we present a detailed rf and beam dynamics design of an 90 Ghz electron source for use as a source of unpolarized electrons for a switched matrix accelerator [1]. RF simulations in both the frequency and time domains were conducted using GdifidL [2]. The beam dynamics simulations were conducted using HOMDYN [2] and ITACA [3]. The design parameters of this injector are listed in Table 1.

2 THEORY

The scaling of a S-band design up to W-band following scaling laws [4] for RF guns brings to on cathode emissivity which are well present state of the art. In fact, since bunch sizes scale like RF wavelength as well as for the bunch charge, that implies that bunch peak current scales invariant while current density scales like the square of the frequency. This leads to a current density in excess of a few MA/cm² if the BNL/UCLA/SLAC [5] gun design is scaled up to 91 GHz (see Table 1). Furthermore, the cathode RF peak field, as well as the solenoid peak field, scale like the frequency leading to a peak field in excess of 3 GV/m and a solenoid peak field of several

Teslas. Because of the tight requirements imposed by a pure scaling, together with the requirement of a laser phase-jitter less than 30 fs, we abandon the conventional scheme for RF guns and adopt a different lay-out.

We follow the scheme presented in [6], where a laser pulse longer than the rf period is sent onto the photocathode surface in order to extract a long electron bunch, typically a quarter of the rf wavelength, carrying a modest current, around 20 A. There is no need for phase stability of the laser in this case, not even phase-locking: the accelerating rf field sets up the time structure for the beam. The scaling up to W-band of the lay-out presented in [6] at 1.3 GHz requires a 1.5 GV/m peak field at the cathode and an 11 ps laser pulse generating 170 pC at the cathode surface, of which only 40 will be extracted from the gun. Since the cathode spot size is 120 microns and the extracted current 10 A, the cathode current density is limited to 20 kA/cm².

	Nominal S-band Parameters	Scaled W-band Parameters	Scaled W-band Long Laser Pulse
Gradient [GeV/m]	0.140	4.5	1.5
Solenoid Peak Field [T]	0.23	7.3	2.5
Charge [nC]	1	0.032	0.166 (use 1/4)
Laser Pulse Length [ps]	10	0.3	11
Laser-rf Phase Jitter [fs]	1000	30	Anything
Cathode Spot Size [μ m]	1000	30	120
Current Density [A/cm ²]	3×10^3	$>10^6$	3×10^4

Table 1: Nominal S-band operating scaled to W-band for both a pure scaling and the proposed long pulse scaling.

The HOMDYN and ITACA simulations shown in Section 4 show that the linear energy-phase correlation at the front part of the bunch (i.e. the first 30 RF deg), can be transformed into a phase compression using an undulator, achieving a current in excess of 600 A in a sharp peak a few RF degrees long.

3 DESIGN AND MECHANICAL FABRICATION

This rf gun is basically a 1.6 cell BNL/SLAC/UCLA S-Band rf gun scaled to 91.324 GHz. Power is symmetrically feed into the full cell which also has

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symmetrical tuners, as does the half cell. The gun is shown in Figure 1.

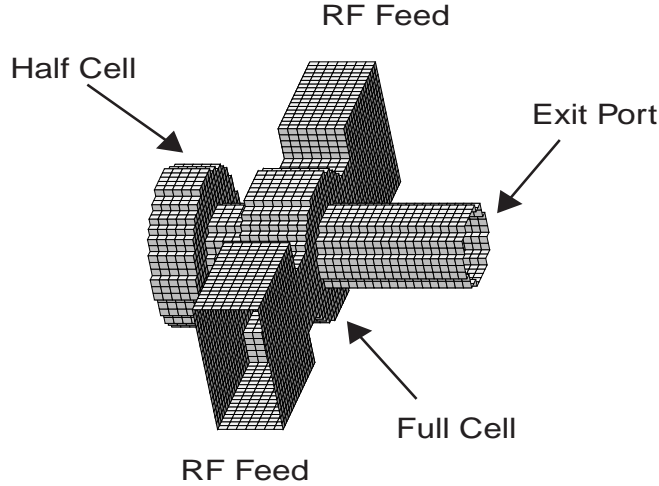


Figure 1: A schematic of the 1.6 cell W-band electron source.

The waveguide to full cell coupling slot is the full height of the full cell. This was decided upon to facilitate the wire EDM manufacturing process. The waveguide feed in the body of the gun is not standard WR-10. The waveguide cutoff dimension is still 2.54 mm or 60 GHz. The waveguide height is slightly smaller at 1.016 mm versus 1.27 mm for standard WR-10 waveguide. This decision was determined by our manufacturing technique of wire EDM and our assembly process of high temperature bonding at the high rf current joints. The gun is manufactured out of 5 layers of Glidcop AL-15 [3] to prevent distortion of the cell to cell and rf coupling iris during the thermal cycle necessary for the bonding. The first of these five layers consists of a cathode plate. A half cell plate, which is the thickness of the half cell which is wired EDM. The third plate is the cell to cell iris. The full cell plate which is slightly thinner than the narrow dimension of WR-10 waveguide. It should be noted that the symmetric waveguide feed does not extend to the boundary of the material. Only after these five layers are bonded does the waveguide extend to the outer body of the gun. This is to facilitate the alignment and assembly of the gun. The last layer is the exit port of the gun. This layer has the same ID as that of the cell to cell iris. The individually layers of the gun are produced out of a single piece of Glidcop AL-15, in which alignment pin hole are first bored in to the block. A section of this block is sliced off to produce the cathode plate with its alignment pins. A wire start hole is popped through the remaining block. The cell to cell iris is wired into the block and then a section of the block is cut off. This section will be used to manufacture the cell to cell iris and the exit port of the gun. One of the blocks is then sliced into thin section a little thicker than the required cell to cell iris thickness. These will be diamond fly cut flat and parallel to facilitate diffusion bonding. Next the other half of the original block will be cut in half and the full cell cavity and waveguide profile will be wired and sliced as was the case of the half cell. These in turn are also diamond fly cut. The assembly is then cleaned and diffusion bonded. At

this point the outer body of the gun is cut to expose the WR-10 waveguide.

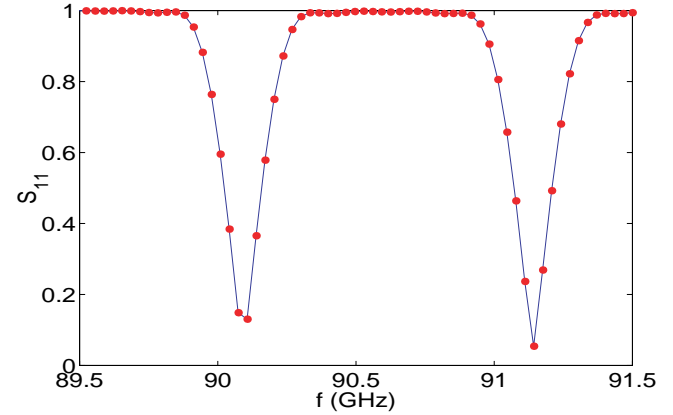


Figure 2: Smith chart representation of GdifiDL simulations of S_{11} .

The rf simulation code GdifiDL was utilized to produce an $S_{11} = 1.00$ with equal fields at the cathode and in the middle of the full cell (see Figure 2). A Smith Chart representation of this match is shown below in Figure 3.

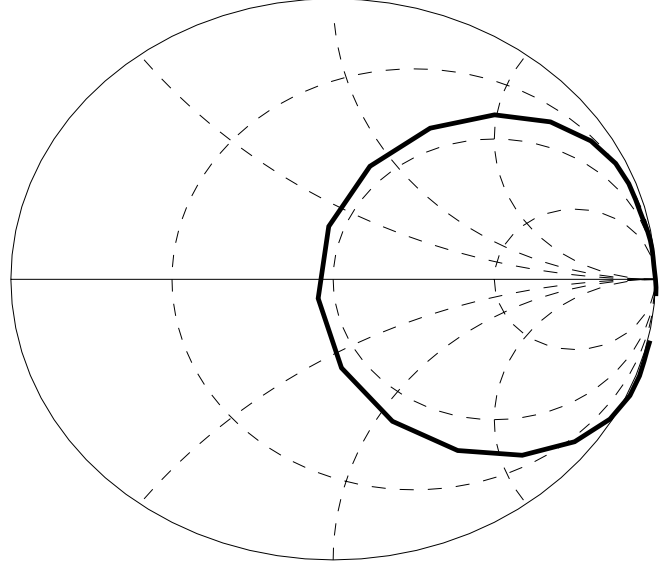


Figure 3: S_{11} of both the 0 and pi-modes.

Using the Shunt impedance calculated from GdifiDL we find that the required power from a W-band rf source will be in excess of 1 GW.

4 SIMULATIONS

In this section we present a possible configuration for a W-band injector based on a preliminary study of beam dynamics in a system consisting of a 1.5 cell W-band gun, followed by a solenoid lens, a SW 8 cell booster linac and a short undulator. The gun is 2.5 mm long, the drift up to the booster is 17.5 mm, the booster is 13 mm, the drift up to the undulator is 12 mm and the undulator is 160 mm (8 periods with 2 cm period length).

In order to achieve a nice phase focusing in the gun we have to use a low value for α (0.8), resulting in 1.5 GV/m peak field at the cathode. The solenoid lens, located

6.3 mm from the cathode (at $z=0$), must provide a 2.5 T peak field. The booster linac is run at 500 MV/m accelerating gradient, while the undulator requires a peak field of 0.5 T.

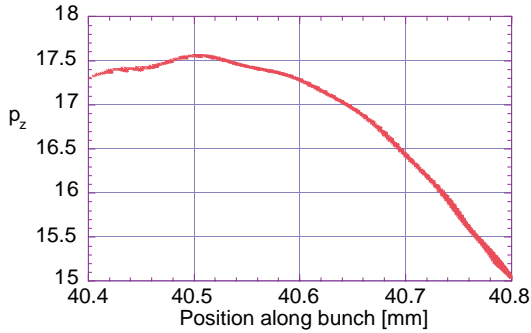


Figure 4: Correlated head of bunch at booster exit.

A bunch charge of 166 pC is produced at the photocathode surface during the illumination of a 11.1 ps laser pulse (as long as the RF period): because of the low α , only the first 65 RF degrees are successfully extracted from the gun, i.e. the first 2 ps of laser pulse lasting from the 0 cathode-field time (0 RF deg) until the 65 RF deg time. The rest of the electrons are either back-accelerated onto the cathode after leaving the cathode surface (those between 65 and 180 RF deg) or not even extracted because of the wrong sign in the applied field (those between 180 and 360). The nominal current in the extracted electron bunch is 15 A (30 pC in 2 ps), implying a cathode current density of 33 kA/cm² at a cathode spot size of 120 microns (as was used in the simulations). The bunch is then focused by the solenoid lens, which is needed to overcome the RF defocusing kick, and injected almost collimated into the booster, which brings up its energy to 7.8 MeV (at the gun exit 1.8 MeV). As a result of the huge phase spread, the energy spread is but nicely linearly correlated in the head part of the bunch (the first 20 RF degrees from $z=40.65$ to $z=40.8$, the bunch has just exited the booster). The effect of phase-focusing, achieved thanks to the operation at low α , brings a density compression in the head part of the bunch, as shown in Figure 4, plotting the local current carried by the bunch, which is much larger than the nominal value in the head part while much lower in the tail: because of the phase-focusing one obtains peak currents around 70 A, a factor 4 larger than the nominal value.

The beam is further injected into an undulator (no other focusing lenses were used in the short drift to the undulator) that acts like a dispersive medium boosting the phase compression mechanism which would take place anyway even in a simple drift, because of the negative correlation in the energy-phase correlation of the bunch (head particles less energetic than tail particles).

In summary, using a long laser pulse and a suitable gradient alleviates the severe restrictions imposed by a

pure scaling on laser-rf phase jitter and cathode current density.

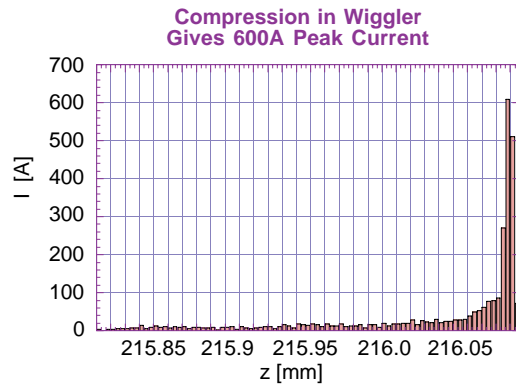
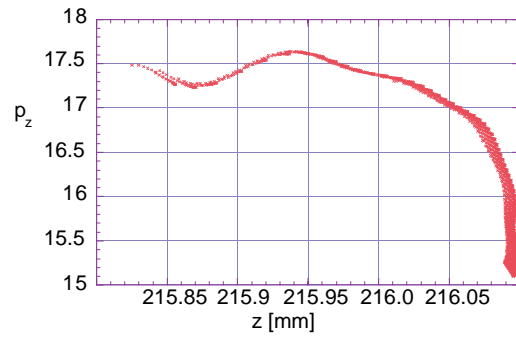
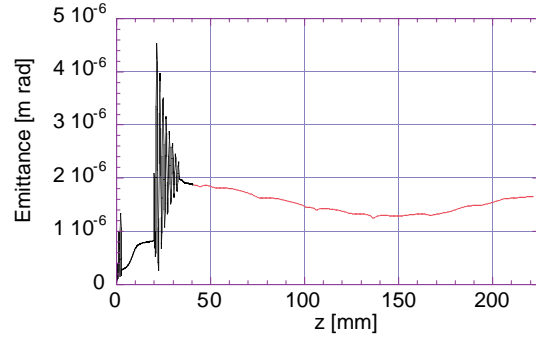


Figure 5: ITACA output of Gun, booster and undulator showing: the beam emittance, longitudinal phase space, and peak current.

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